A STUDY ON THE VALIDITY OF BUOY MOUNTED ACOUSTIC DOPPLER PROFILERS: A COMPARISON OF UPWARD AND DOWNWARD LOOKING SYSTEMS IN ONSLOW BAY, NC

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Abstract- **The National Data Buoy Center (NDBC) maintains an extensive array of moored buoys around the world. Hence, mounting Acoustic Doppler Current Profilers (ADCPs) to these buoys has proven to be an avenue worth exploring. In a previous study done by Seim and Edwards [1], a downward-looking ADCP from NDBC buoy 41008 was compared to an upward-looking ADCP from the University of North Carolina at Chapel Hill (UNC) located in close proximity to test the validity of ADCP measurements made by a buoy-mounted ADCP. Since configurations of the systems were not standard, the two did not agree well. Since this time, NDBC has made several changes to the configuration of their ADCPs. This study is to again compare a NDBC downward-looking ADCP mounted to buoy 41036 to an upward-looking ADCP from the University of North Carolina at Wilmington (UNCW) mounted on the seafloor to test the reliability of NDBCs present buoy-mounted ADCP configuration. Both of these systems are located on the shallow continental shelf of Onslow Bay, North Carolina. An 18-day time series was obtained from each ADCP. Preliminary results show good agreement between the two systems. In light of the fact that the buoy-mounted system is subjected to movement by atmospheric and oceanic processes, further data conditioning is investigated to see if more precise environmental thresholds, specifically wave height thresholds, can be put in place for more accurate current measurements.**

I. INTRODUCTION

The National Data Buoy Center (NDBC) has two methods for mounting Acoustic Doppler Current Profilers (ADCPs) to a buoy, mounting the ADCP in the bridle of the buoy and mounting the ADCP in an in-line mooring cage. Each of these configurations has its own drawbacks. One of the biggest concerns with data quality of a buoy-mounted ADCP is the effect that buoy motion has on current readings. In a study by Seim and Edwards [1], two systems located in close proximity to one another, a downward-looking ADCP from NDBC buoy 41008 and an upward-looking ADCP from the University of North Carolina at Chapel Hill (UNC) were compared to test the validity of ADCP measurements made by the buoy-mounted ADCP. The buoy-mounted ADCP's sampling rate and bin size were not optimal. It was also suggested that the in-line mooring cage in which the buoy-mounted ADCP was deployed responded differently to wave motion than the buoy responded, and therefore corrections applied for pitch and roll might be incorrect. The study showed the two systems did not agree well, but because the configurations between the two were not standard, it was not conclusive that the disagreement was due to biases induced from buoy motion. Since the study by Seim and Edwards [1], NDBC has made several changes to the configuration of its buoy-mounted ADCP sampling rate and bin size. This study is to again compare an NDBC downward-looking ADCP mounted to buoy 41036 to a nearby upward-looking ADCP from the University of North Carolina at Wilmington (UNCW) mounted on the seafloor to test the reliability of NDBC's present buoy-mounted ADCP configuration. NDBC buoy 41036 and the UNCW ADCP are located on the shallow continental shelf of Onslow Bay, North Carolina.

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II. MOORING METADATA

Each instrument was deployed in the northern portion of the South Atlantic Bight (SAB) in Onslow Bay, North Carolina. The shelf width in Onslow Bay is roughly 100 kilometers, with the shelf break occurring at the 70-meter isobath. Onslow Bay is bordered by two shoal areas, Cape Lookout Shoals to the north and Frying Pan Shoals to the south. Except in the two shoal areas, the bathymetry in Onslow Bay is relatively smooth. The upward-looking and downward-looking ADCPs were deployed approximately 50 nautical miles from Wrightsville Beach, North Carolina in about 30 meters of water (see Fig. 1). The waters in which the instrumentation is located are significantly influenced by atmospheric forcing and tidal action. The Gulf Stream affects waters generally seaward of the 100-meter isobath but has been seen to affect waters as close as the 45-meter isobath [2]. Two time spans of data have been recovered for both NDBC's downward-looking and UNCW's upward-looking ADCP: March 10, 2008 – March 28, 2008 and May 4, 2008 – May 10, 2008. Only the dataset from March 10, 2008 – March 28, 2008 will be examined at this time. Approximately 400 hours of observations were collected from this dataset for this study.

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14. ABSTRACT

The National Data Buoy Center (NDBC) maintains an extensive array of moored buoys around the world. Hence, mounting Acoustic Doppler Current Profilers (ADCPs) to these buoys has proven to be an avenue worth exploring. In a previous study done by Seim and Edwards [1], a downward-looking ADCP from NDBC buoy 41008 was compared to an upwardlooking ADCP from the University of North Carolina at Chapel Hill (UNC) located in close proximity to test the validity of ADCP measurements made by a buoy-mounted ADCP. Since configurations of the systems were not standard, the two did not agree well. Since this time, NDBC has made several changes to the configuration of their ADCPs. This study is to again compare a NDBC downward-looking ADCP mounted to buoy 41036 to an upward-looking ADCP from the University of North Carolina at Wilmington (UNCW) mounted on the seafloor to test the reliability of NDBCs present buoy-mounted ADCP configuration. Both of these systems are located on the shallow continental shelf of Onslow Bay, North Carolina. An 18-day time series was obtained from each ADCP. Preliminary results show good agreement between the two systems. In light of the fact that the buoy-mounted system is subjected to movement by atmospheric and oceanic processes, further data conditioning is investigated to see if more precise environmental thresholds, specifically wave height thresholds, can be put in place for more accurate current measurements.

15. SUBJECT TERMS

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Each mounting is equipped with an RD Instruments 300-kHz Workhorse Sentinel with 20˚ beam angle transducers [3]. Specifications of sampling for each mooring are given in Table I. For the bottom-mounted system, the ADCP was mounted so that the transducer heads were 70 centimeters above the seafloor. The buoy-mounted ADCP is in the bridle-mount configuration, with the ADCP ~2 meters below the buoy-hull (see Fig. 2). NDBC shows the average water depth of the area to be ~30.8 meters. This water depth was used to calculate the location of UNCW's bins since a pressure recorder was not used in these particular deployments.

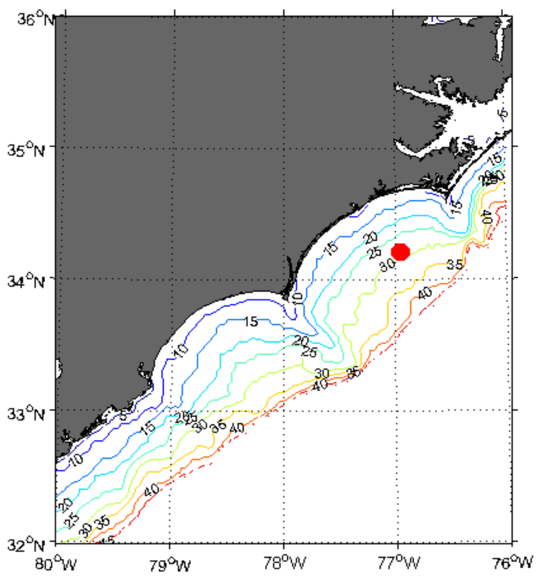

Figure 1: Map of the focus area, with isobath contours overlaid. The labels on the contours are given in units of meters. The red dot indicates the location of buoy 41036.

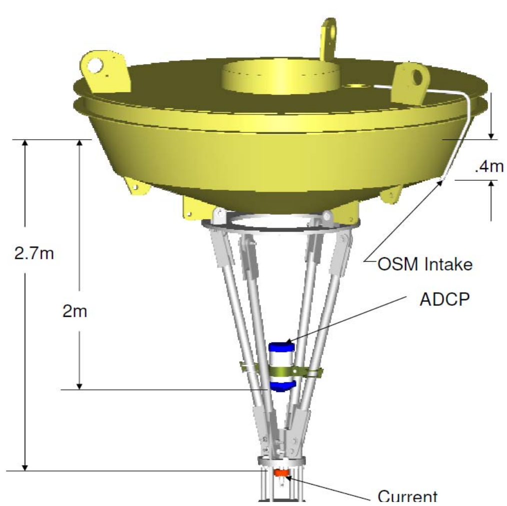

Figure 2: Schematic of an ADCP in a bridle-mount configuration

TABLE I

CONFIGURATION INFORMATION FOR BOTTOM- AND BUOY-MOUNTED 300 KHZ ADCPS

	Bottom-Mounted	Buoy-Mounted
Sampling Frequency	1 per hour	1 per hour
Sampling Interval	1.5 sec	1.5 sec
Number of Samples	200	200
Time between ensembles	2 hours	2 hours
Bin size	2 m	2 m

III. METHODS

To obtain more accurate across- and along-shelf velocity measurements, all u and v components were rotated 62˚ clockwise to align the coordinate system with the isobaths, which run approximately parallel to the coastline. Bins from each mooring differ by about 0.8 meters, with the center of the shallowest bin for the bottom-mounted ADCP at 3.78 meters and the center of the shallowest bin for the buoy-mounted ADCP at 3.1 meters, with the center of each successive bin 2 meters away. Bins were not spatially interpolated to account for this difference. This could be a source for some minor discrepancies found between the moorings but should not significantly affect the overall results of the study. Echo amplitudes were examined to determine which bins were receiving interference from the sea surface and the seafloor. Generally, echo amplitudes decrease in magnitude as distance from the transducer head increases. Bins with echo amplitudes showing deviating behavior from this trend are likely being affected by interference from the bottom, surface, or the buoy itself. Bins showing interference from the sea surface and seafloor were not used in the analysis. Data with error velocities in excess of 10 cm/s were also removed from the dataset. These and missing values were interpolated using a linear method. Only bins 1 through 11 from the downward-looking ADCP and bins at corresponding depths from the upward-looking ADCP (bins 3-13) were used in this comparison. Approximately 9% of NDBC's dataset was removed based on excessively high error velocity values. All data referred to as "raw" have been pre-processed in the manner described above.

IV. OBSERVATIONS

From the raw data plots shown in Fig. 3 it can be seen that both systems are capturing the same overall gross trends. For brevity, only plots for the 15 meter bin are shown. Across- and along-shelf correlations are 0.945 and 0.984, respectively. All bins were examined, and statistics will be given for a near-surface (5m) and a near-bottom bin (23m). The across- (along-) shelf correlations are 0.951 (0.986) and 0.935 (0.981) for the near-surface and near-bottom bins, respectively.

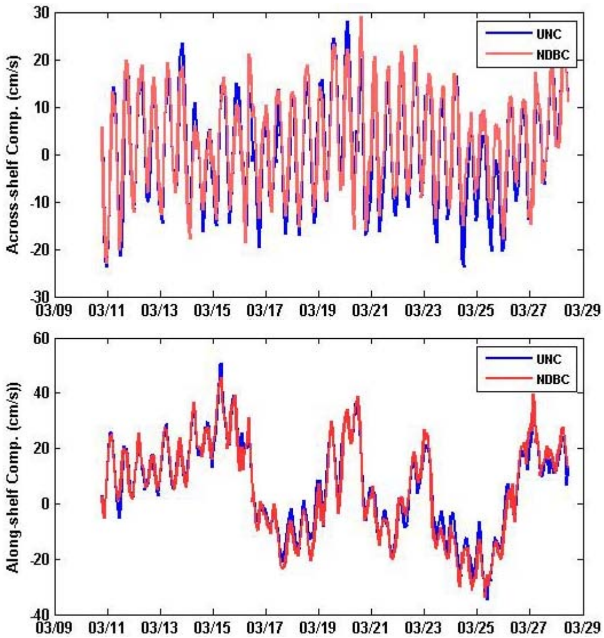

Figure 3: Raw data time-series for the across- (top) and along-shelf (bottom) velocity components for the buoy- and bottom-mounted ADCPs at the 15-m bin.

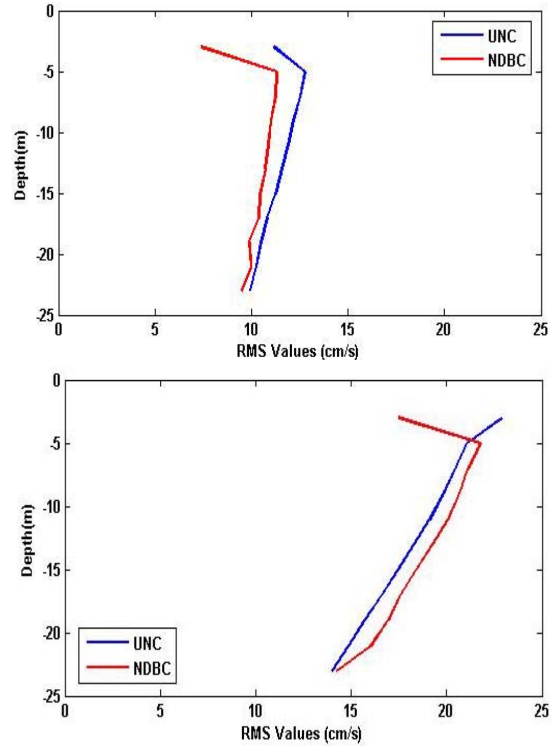

Figure 4: RMS profiles for the across- (top) and along-shelf (bottom) velocity components of both ADCP systems.

Root mean square (RMS) profiles with depth (see Fig. 4) show good agreement between the two systems excluding the first bin (3m), which shows a significant reduction in RMS values. This strange behavior noted at the top of the water column was illustrated in ADCP studies done by Seim and Edwards [1] and also by Mayer et al. [4]. It must be noted that this effect is captured by both the bottom- and buoy-mounted systems and is most likely a result of interference from the surface or the buoy itself. Mean differences in RMS values between the two systems are less than 1 cm/s for the entire depth profile. Seim and Edwards [1] found that RMS values for the buoy-mounted system were four times greater than the values of its bottom-mounted counterpart. This study shows the RMS values of the buoy-mounted system have been greatly reduced and are comparable to the values produced by the bottom-mounted system. Mean values of all RMS data are below the standard deviation of the ADCP given by RD Instruments of ~4 cm/s [3].

Fig. 5 shows depth profiles of mean and standard deviation for across- and along-shelf components for both bottom- and buoy-mounted systems. Across- and along-shelf means compare well. The strange behavior at the top-most bin which was noted in Fig. 4 is also present in Fig. 5. Fig. 6 shows scatter plots of the means with depth which indicate a very small positive bias of ~2 cm/s for across- and ~0.5 cm/s for along-shelf velocities. The slopes of the regression lines show that the buoy-mounted system slightly over-predicts across- and slightly under-predicts along-shelf components. A time-series plot of the direction and magnitude at a top, middle, and bottom bin in Fig. 7 shows both of the systems capture the overall circulation patterns with no obvious deviations.

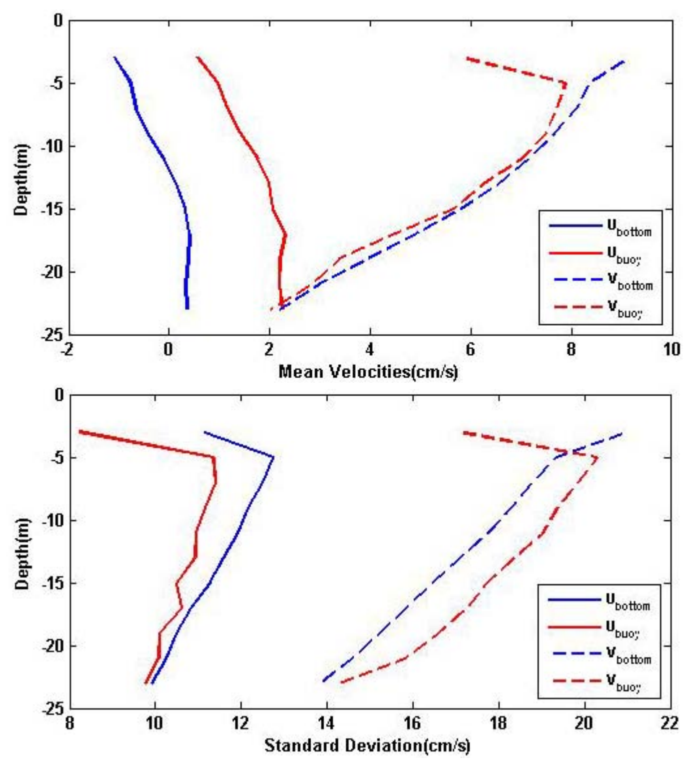

Figure 5: Mean and standard deviations of velocities with depth shown in the top and bottom panels, respectively. Bottom- (blue) and buoy-mounted (red) across- (solid line) and along-shelf (dashed line).

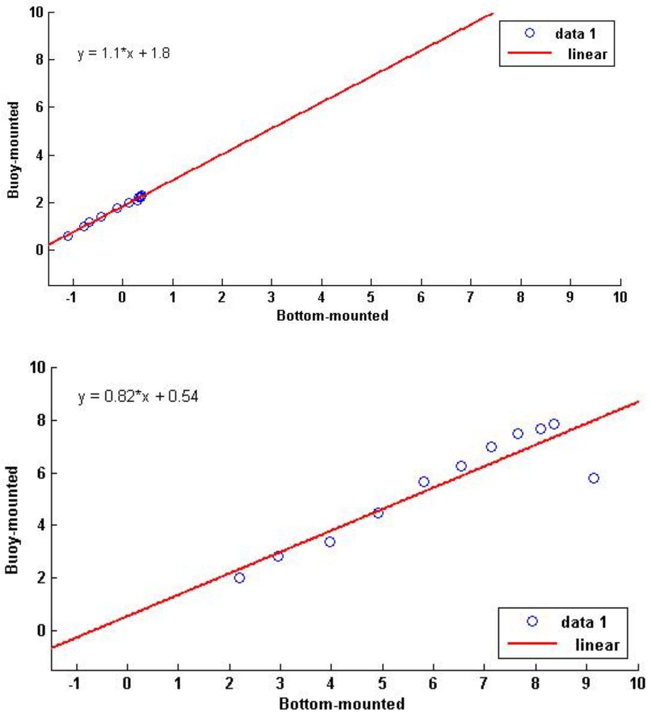

Figure 6: Scatter plot of mean velocities for across- (top) and along-shelf (bottom).

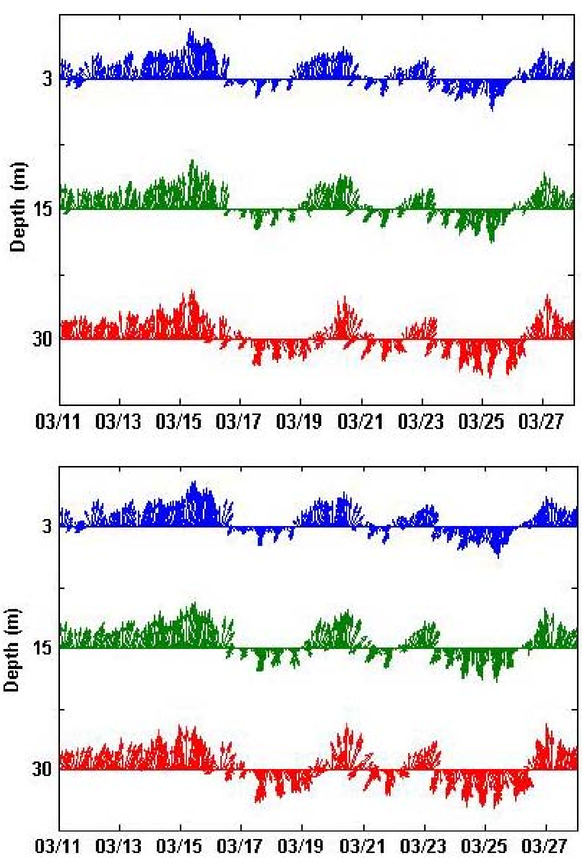

Figure 7: Current vectors for the complete time-series. Bottom- and buoy-mount shown on top and bottom, respectively.

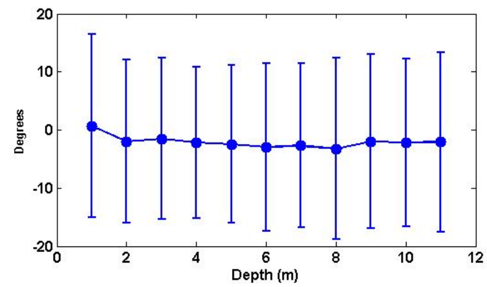

Figure 8: Mean and Standard deviation of the differences between current directions recorded by NDBC and UNCW ADCPs.

Now that it has been shown that each ADCP is capturing overall trends, data will be filtered to show the response of the bottom- and buoy-mounted systems to tides and winds, the two main players in this environment.

V. TIDAL DATA

The SAB is dominated by the M_2 semi-diurnal tidal component. Tidal ellipse major axes are directed cross-shore while minor axes are directed along-shore. Minor axes velocities are about half that of major axes [5]. The M_2 semi-diurnal tide also accounts for ~80% of the kinetic energy on the inner and mid shelf [6]. Based on this fact alone, recording a correct tidal signal is a great confirmation that each system is capturing the real-world environment in which it is located.

Data were filtered using a 4^{th}-order butterworth filter in order to isolate tidal frequencies. Specifically, data were passed through a 10-hour low-pass filter followed by a 30-hour high-pass filter. Fig. 9 shows the comparison of auto-spectra for the cross- and along- shelf components for each system. Again, for brevity only plots for the 15-meter bin are shown. Correlation coefficients between NDBC and UNCW datasets are 0.982 and 0.971 for the cross- and along-shelf components, respectively. Correlation coefficients for near-surface and near-bottom bins do show slight decreases but still exhibit high correlation values well above the 90% mark.

Tidal phase and inclination, computed with the T-Tide Matlab package [7] show very good agreement between NDBC and UNCW ADCPs (see Table II). The M_2 tide is verified as being the dominant tidal component in this area as noted by the very large signal-to-noise ratios (SNR). Differences in phase and inclination of the M_2 and K_1 constituents between bottom- and buoy-mounted ADCPs are neglible, between 1-2˚. One interesting thing to note is that the M_2 SNR of the 5-meter bin for the buoy-mounted ADCP is two orders of magnitude lower than the bottom-mounted system, suggesting that the buoy-mounted system is subjected to greater ambient noise from the atmosphere and wave motion at its topmost bins. The O_1 and S_2 tidal constituents show greater disagreement with depth with phase offsets upwards of 20 degrees and inclination offsets of ~10 degrees.

TABLE 2

HARMONIC ANALYSIS RESULTS

5m

Tide	Freq. (cph)	Major Axis (cm/s)	Minor Axis (cm/s)	Inclin. (˚)	Phase (˚ relative to Greenwich)	SNR
O1	0.0387307					
Bottom		2.438	-0.235	110.60	311.59	2.1
Buoy		2.1996	-0.823	110.88	309.87	1.3
K1	0.0417807					
Bottom		4.538	-1.775	72.61	195.20	4.3
Buoy		4.309	-2.334	93.13	193.10	3.3
M2	0.0805114					
Bottom		14.173	-6.339	17.77	317.61	120.0
Buoy		13.384	-6.111	19.13	318.50	94.0
S2	0.0833333					
Bottom		3.536	-1.080	11.42	52.76	8.4
Buoy		3.447	-1.289	13.94	48.15	7.9

15m

Tide	Freq. (cph)	Major Axis (cm/s)	Minor Axis (cm/s)	Inclin. (˚)	Phase (˚ relative to Greenwich)	SNR
O1	0.0387307					
Bottom		1.929	-0.590	97.67	325.10	1.3
Buoy		1.631	-0.473	98.85	307.13	0.88
K1	0.0417807					
Bottom		3.037	-0.299	68.16	219.31	1.9
Buoy		4.030	-1.289	86.70	231.70	4.1
M2	0.0805114					
Bottom		13.471	-6.665	17.01	319.31	1600
Buoy		13.093	-6.270	18.79	317.45	1600
S2	0.0833333					
Bottom		3.531	-1.231	19.43	45.46	7.9
Buoy		3.411	-0.913	14.91	42.26	15.0

23m

Tide	Freq. (cph)	Major Axis (cm/s)	Minor Axis (cm/s)	Inclin. (˚)	Phase (˚ relative to Greenwich)	SNR
O1	0.0387307					
Bottom		0.999	-0.264	141.11	322.33	1.0
Buoy		1.162	0.219	156.26	261.77	1.5
K1	0.0417807					
Bottom		1.846	0.221	91.04	261.93	1.8
Buoy		2.309	-1.173	110.57	255.43	2.0
M2	0.0805114					
Bottom		12.379	-4.768	15.52	312.34	3700
Buoy		11.555	-3.639	13.88	312.78	2900
S2	0.0833333					
Bottom		3.177	-0.961	12.45	34.03	18.0
Buoy		3.181	-0.914	1.92	20.60	16.0

VI. WINDS

Typically during the fall and winter, the entire water column of the shelf in the SAB becomes well mixed, homogenous throughout. Lentz [8] showed that the stratification of the water column plays a significant role in the wind-driven nature of the sub-tidal cross-shelf flow. Particularly, it was found when waters are unstratified, the cross-shelf flow is substantially reduced even when wind stresses are high. This fact is illustrated by Fig. 10, where it is seen that cross-shelf velocity magnitudes are a great deal less than the along-shelf magnitudes.

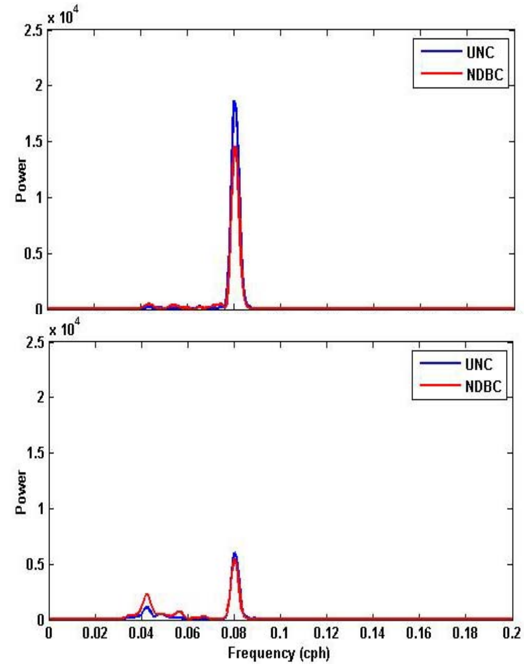

Figure 9: Tidal spectra for the across- (top) and along-shelf (bottom) of band-pass filtered velocity components.

Low-frequency correlations for the along-shelf component, the dominant signal is this band, are 0.997, 0.994, and 0.994 for the near-surface, mid-column, and near-bottom bins, respectively. The mean differences found between bottom- and buoy-mounted systems in the along-shelf component for these bins range between 1 and 2 cm/s. Correlations for the cross-shelf component are not as good and show a decreasing trend away from the mid-bin in both directions. The mean differences for the cross-shelf component range between 2 and 3 cm/s.

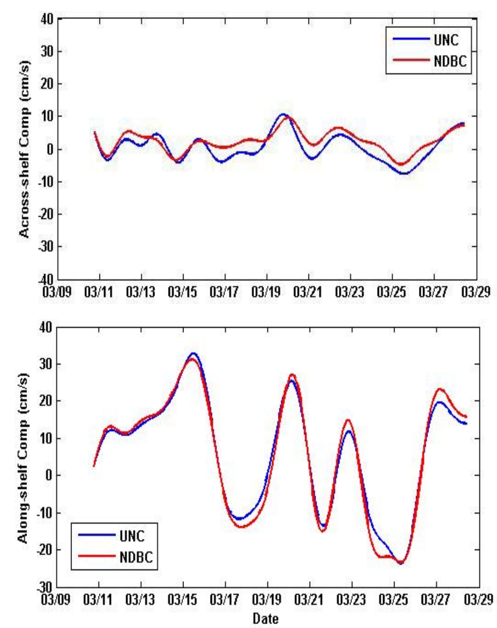

Figure 10: Time-series of 40-hr low-pass filtered data for across- (top) and along-shelf (bottom) velocity components.

VII. Data Conditioning

In a paper by Crout [9], it was shown that buoy-mounted ADCPs do have a wave height threshold for reporting reliable data. However, it was only possible to give a threshold range between 3 and 6 meters because wave heights grew quickly over such a short time frame. There is a brief interval in the dataset from this study where wave heights exceed 3 meters, March 20-March 21 2008, which can be seen in Fig.11. The disagreement between the bottom- and buoy-mounted systems is quite obvious during this interval, which suggests the wave height threshold to be toward the lower limit of the range reported by Crout [9]. Although more than 50 percent of these data points have correspondingly high error velocities and would have been taken out in pre-processing, taking out data points where corresponding wave heights are greater than 3 meters will in most cases improve data. It also appears high wind speeds alone are not enough to affect the quality of buoy-mounted current observations.

VIII. Conclusion

Overall, it is seen that the buoy-mounted system captures the general circulation patterns in the area. Raw data comparisons of across- and along-shelf components between the two systems agreed very well, exhibiting high correlation coefficients and low mean differences. Raw data time-series plots of current direction and magnitude show that buoy motion induced no obvious bias in its directional current data. Harmonic analysis shows that the phase and inclination of the M_2 tide, the dominant tidal component in this area, as well as the K_1 tidal component, show very little difference (1-2˚) between bottom- and buoy-mounted systems. It was seen that the top bins of the buoy-mounted ADCP are subjected to greater ambient noise from its surroundings than the bottom-mounted system, as is evident by the much lower SNR of the M_2 tidal component. Low-frequency data, across- and along-shelf, are in good agreement at the mid-bin as well as in the near-top and near-bottom bins for the along-shelf component. Agreement decreases in both directions away from the mid-bin for the low-frequency cross-shelf component. This departure is possibly due to the low velocities experienced in the across-shelf direction.

We believe this study shows that buoy-mounted ADCPs do produce accurate current measurements. The analysis shows buoy-mounted measurements to be comparable its bottom-mounted counterpart. Although the buoy-mounted system is subjected to the continuous movement of its platform induced by weather and waves, it was found that these motions do not impair the sensors ability to record accurate direction and magnitude information about the currents in general as well as in the tidal and low-frequency band.

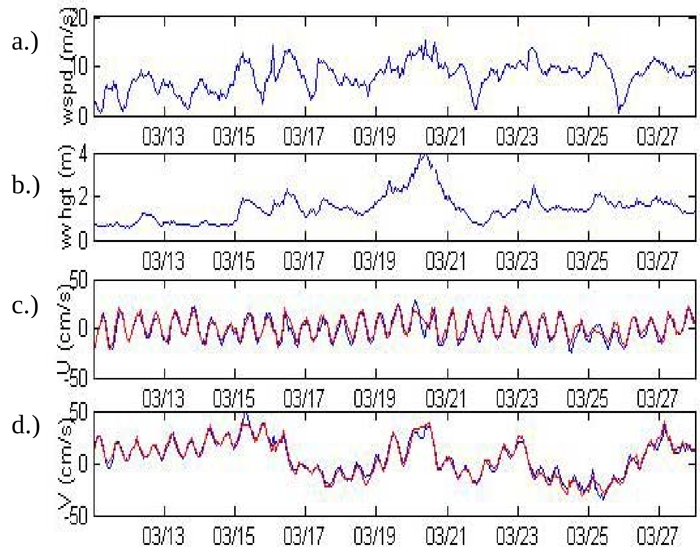

Figure 11: Panels a and b show wind speed and wave height as recorded on NDBC buoy 41036. ADCP measured across- and along-shelf components are given in c and d.

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